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Renewable energy supply chains, performance, application barriers, and strategies for further development

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ABSTRACT

Due to the depletion of traditional energy resources, such as crude oil, coal, and natural gas, many initiatives all over the world have addressed the efficient use or replacement of these resources. Several renewable energy sources have been introduced as alternatives to traditional sources to protect environmental resources and to improve the quality of life. This study assesses renewable energy sources from a supply chain perspective and presents an investigation of renewable energies focusing on four main components: renewable energy supply chain, renewable energy performance, and barriers and strategies to its development. The study provides managerial insights to governments, researchers, and stakeholders for the initiation of renewable energy use, and suggestions for overcoming the barriers to its development.

Contents

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1. Introduction

Although traditional power generation has satisfactorily supported residential and industrial needs for centuries, it is losing its advantage due to environmental and economic concerns. Renewable energy (RE) has become a driving force in the effort to sustain the earth's natural resources and to improve the users' quality of life. RE can be defined as a free source of sustainable energy, such as wind or solar energy that produces no negative impacts during conversion process like the emission of hazardous substances. Recent eco-consciousness agendas in many countries have set goals for the development of RE, specifically for its efficient generation and conversion to a consumable form of energy and its commercialization in the market. However, higher conversion costs, limited locations, environmental impacts, and other factors pose barriers to such development. To surmount these barriers, governments, researchers, and stakeholders should work together to enhance the conversion efficiency of RE, develop advanced storage technologies, control distribution efficiency, and commercialize the use of RE ultimately.

This paper assesses the RE from a supply chain (SC) perspective to identify the values of each node in the flow as well as the limitations and breakthrough points comparing with the current electric power generation system. To this end, this paper presents an objective study that examines the four main components of RE business: RE supply chain, RE performance, and barriers and strategies to its development.

The paper is organized as follows: Section 2 enumerates the types of RE; the Renewable energy supply chains section illustrates the flows and issues of the RE supply chain; Section 4 discusses the performance of RE; Sections 5 and 6 consider the barriers and strategies to the development of RE, respectively; and Section 4 presents the conclusions drawn from the study.

2. Renewable energy resources

Several RE resources have been developed and successfully implemented. A secondary process that converts RE into other energy resources is required to fully utilize RE in a variety of applications. This section describes biomass, hydropower, geothermal, wind, and solar energy sources and process flows.

2.1. Biomass

Biomass encompasses a variety of organic resources, such as wood and other plant-based materials from agricultural, forestry, and industrial waste [1]. Several technological processes are available to convert this waste into usable energy resources and products, such as ethanol, biodiesel, electric power, and plastics. For example, biomass can be converted to provide an electric power source for automobiles. Fig. 1 illustrates the biomass energy flow [2].

Given the diversity of biomass resources, its applications are not limited to the production of fuel or electricity; subsidiary products can also be produced during the conversion process. Fig. 2 shows that biomass energy can be converted into fuel, electricity, and heat using three main conversion technologies [3]: thermochemical, biochemical, and extraction processes.

2.2. Hydropower and tidal/wave energy

Rain and seawater are valuable for a wide range of uses. Electric power generated by the flow of water through mills or turbines is widely used in industrial, agricultural, and residential applications. Besides generating electric power, water also acts as a coolant in power-plant operations or hydroelectric dams and can support other industrial operations, such as fuel extraction and refining processes [4]. Hydropower can also be generated by the conversion of tidal or wave action. Since tidal and wave is constantly moving, a storage system is required to conserve energy during off-peak hours. Fig. 3 illustrates the hydropower process flows [4–6].

2.3. Geothermal energy

Although there is no standard definition for geothermal energy, Dickson and Fanelli [7] stated that "geothermal" refers to all the thermal energy stored between the earth's surface and a specified depth in the crust. According to Pearl [8], the resources of geothermal are classified into water, heat, and minerals. The heat can be converted into other energy forms in accordance with the depth of the earth to support various usage purposes. (see Fig. 4).

Besides directly utilizing heat resources, as with other RE sources, heat energy has to be converted into another energy form in order to be used in industrial and agricultural purposes. Heat-pump systems can reserve geothermal energy, facilitating the balance of low and high demand peaks. Electricity generation is widely used to support residential or industrial daily usage. However, the acquisition of geothermal energy is restricted to certain locations in order to realize most of its efficiency outcome. Its collection and conversion require large financial and technological investments as well. Fig. 5 shows the process flows of geothermal energy [9–12].

2.4. Wind energy

Wind energy is not new and had been used to pump water in farms for many years. Following the RE development, wind turbines have been widely selected to generate electric power. Many wind turbines are located in offshore in order to collect massive wind power and to lower the environmental impact on land usage. With the support of technology, smaller wind turbine has been developed

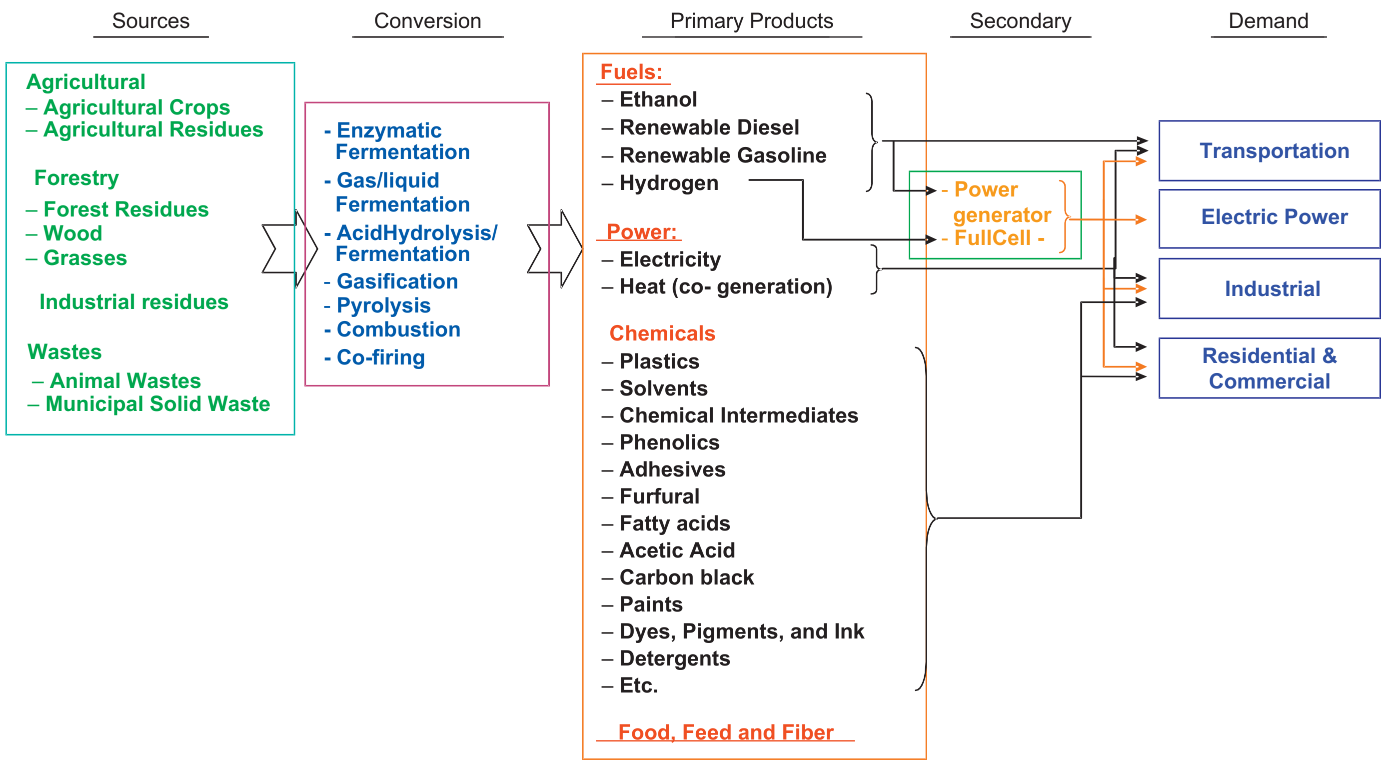


Fig. 1. Biomass energy flows [2].

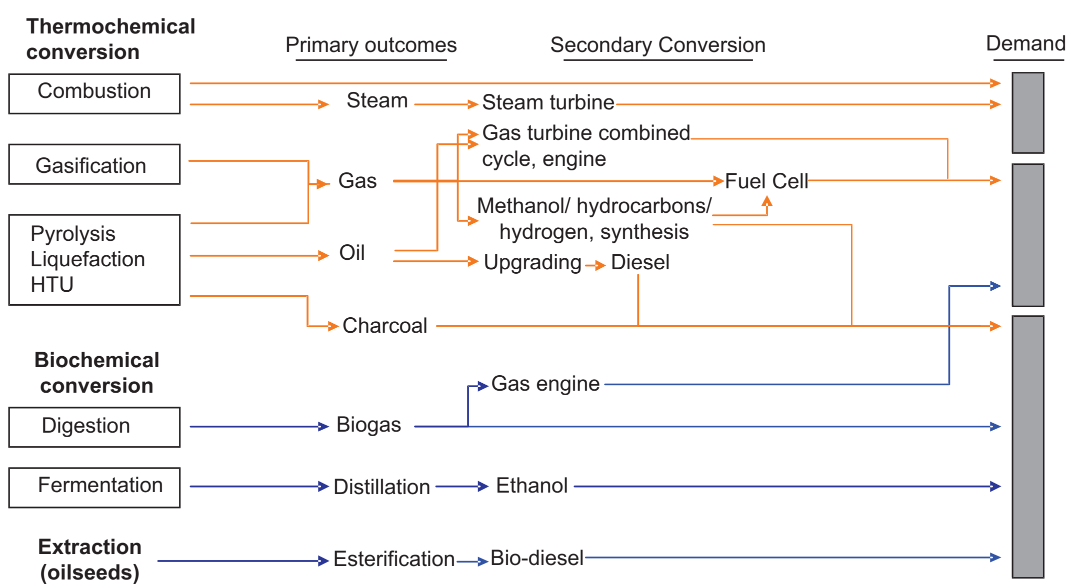


Fig. 2. Biomass conversion technologies and outcomes [3].

to generate energy in urban areas. However, wind strength is unpredictable and dynamic; hence it must be stored to balance electricity demand cycles. In addition, wind energy can couple with solar or hydropower energy for a constant and stable energy source. Fig. 6 shows the wind energy generation flows [13].

2.5. Solar energy

Solar power is an important and widely used RE type. Solar radiation and heat are converted into solar energy, which is used to generate electric power. This RE source is abundant, especially in tropical countries. Besides being used in electric power generation, solar energy has been used widely to supply electric power to many personal portable devices. This RE type is more flexible than the other RE sources, and its initial setup requires a relatively small investment. However, energy storage is essential to supply energy demands in the absence of sunlight. Fig. 7 shows the solar energy generation process flows [14].

3. Renewable energy supply chains

The resource of RE is enormous and inconstant. It is always changing and unpredictable due to uncontrollable weather

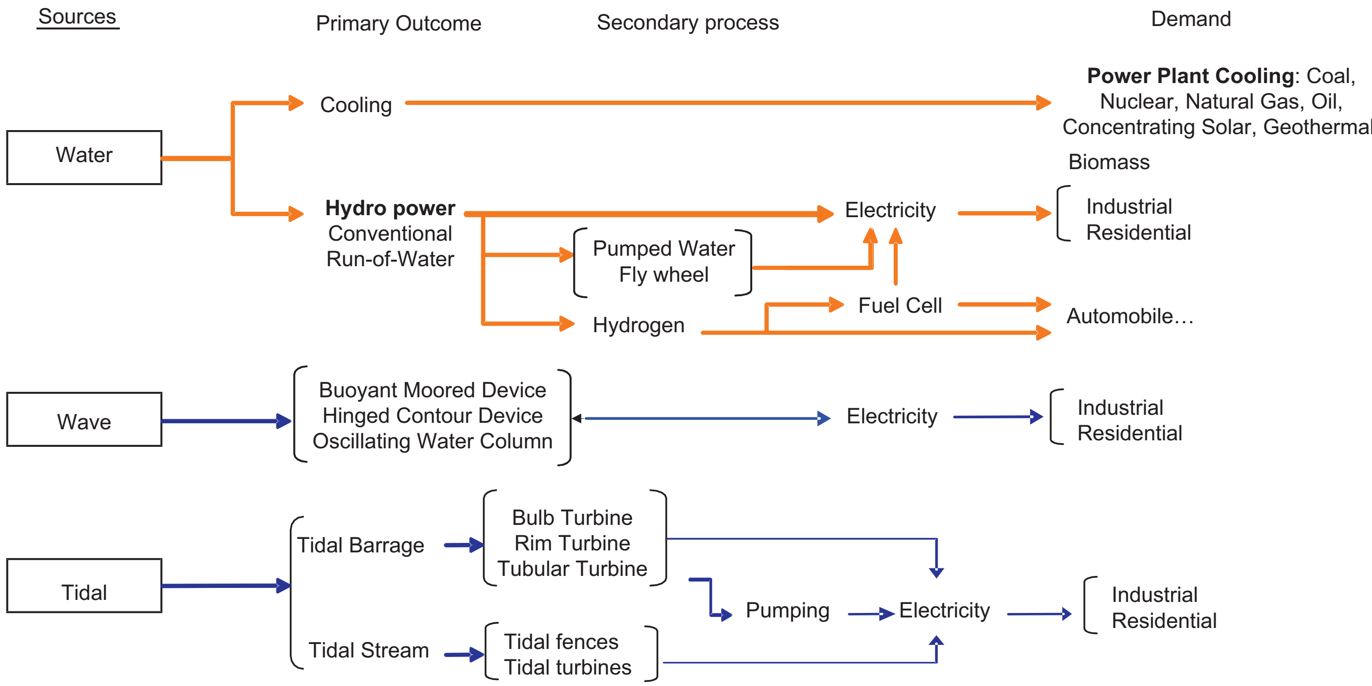


Fig. 3. Types of hydropower process flow [4–6].

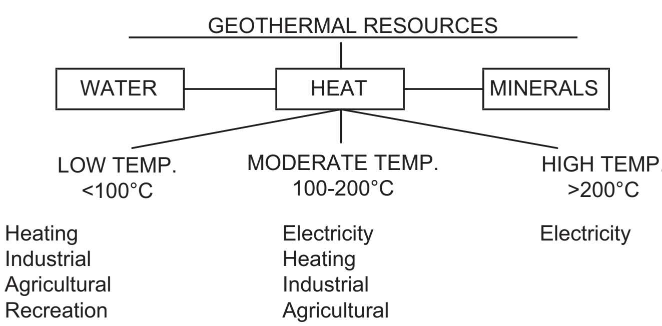


Fig. 4. Geothermal resources [8].

conditions and other factors in which the RE resources are dependent. With this, the utilization and distribution of RE are the major tasks in the RE supply chain.

3.1. Supply chain process flows

Like many typical supply chains, the elements of RE supply chain include the physical, information, and financial flows. From physical flow perspective, industries increasing awareness of green manufacturing processes, logistics, and products has become relevant to its supply chain management performance. These issues have drawn the attention of many researchers, due to the potential contribution of RE to the alleviation of global environmental problems. Ilgin and Gupta [15] have reviewed environmental conscious manufacturing and product recovery researches. They classified more than 540 published studies into four categories of research: environmentally conscious product design, reverse and closed-loop supply chains, remanufacturing, and disassembly. Fig. 8 presents a pure RE supply chain flow presented by the United Nations Development Programme [16]. Electricity is portrayed as an example in this supply chain flow to illustrate the relationships within the loop. In the RE supply chain, technology is a key success factor to improve efficiency and to innovate the distribution network.

In terms of demand, the commercialization of RE would be an important step to replace traditional fossil energy. As such, efficient RE generator and storage technologies are the crucial innovations for RE.

3.2. Renewable energy supply chain issues

Like traditional sources of electric power generation, each RE type is limited by the inherent characteristics of the energy source. Intermittency, variability, and maneuverability are three key variables of RE resources that require effective management and control. In addition, due to the nature of RE, a second conversion process to save energy for use in off-hours is necessary. Fig. 9 shows the factors in the use of RE resources for each stage in the RE supply chain [17–19].

4. Performance of renewable energy supply chains

The RE supply chain links the source of energy with other applications. The performance of RE supply chain relates to its conversion efficiency which includes storage, distribution, efficiency and secondary applications efficiencies.

4.1. Conversion efficiency

Conversion efficiency, considered as a key indicator for the use of a given energy resource, differs among the RE types. Costs associated with primary energy sources such as fossil fuels are critical. Present efforts to reduce the cost of RE acquisition and use through technological improvements may not be sufficient to compete with the fossil-fuel energy production. Fig. 10 displays the energy technology cost and performance data for all REs.

In order to assess the investment for RE, a "Levelized Cost of Electricity" (LCOE) has been identified for decision making in solar energy project. The U.S. Department of Energy's (DoE) Energy Efficiency and Renewable Energy publication [20] has listed higher (LCOE) costs for photovoltaic (PV) and concentrated

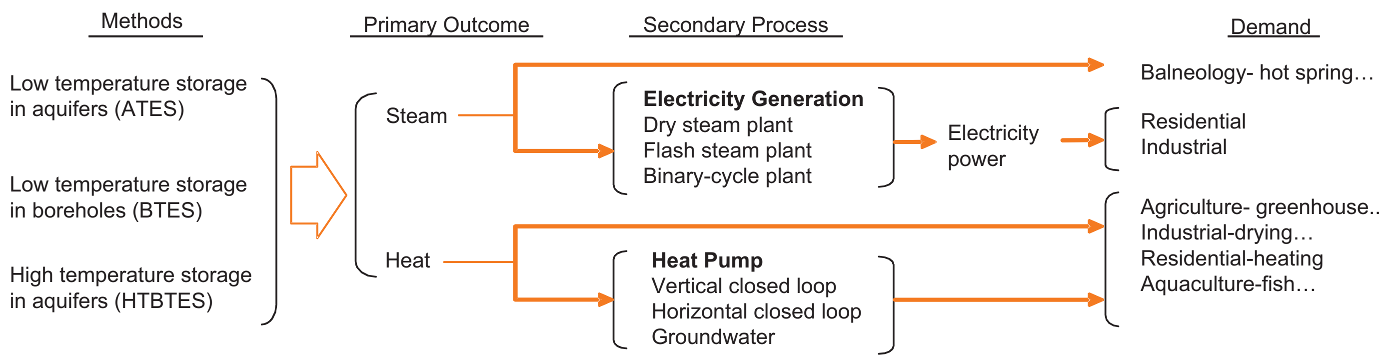


Fig. 5. Geothermal energy process flows [9–12].

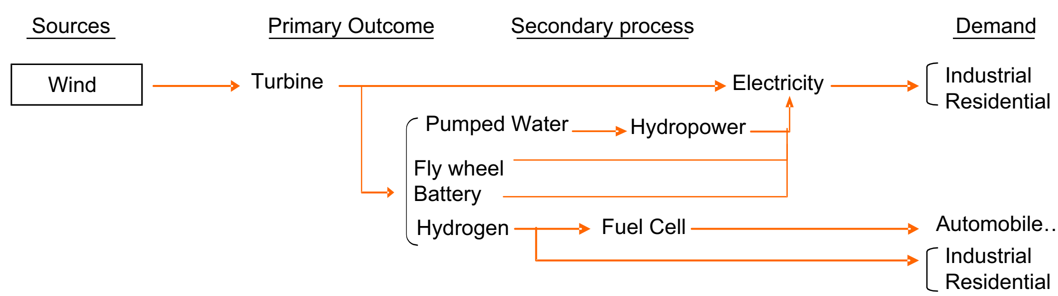


Fig. 6. Wind energy generation flows [13].

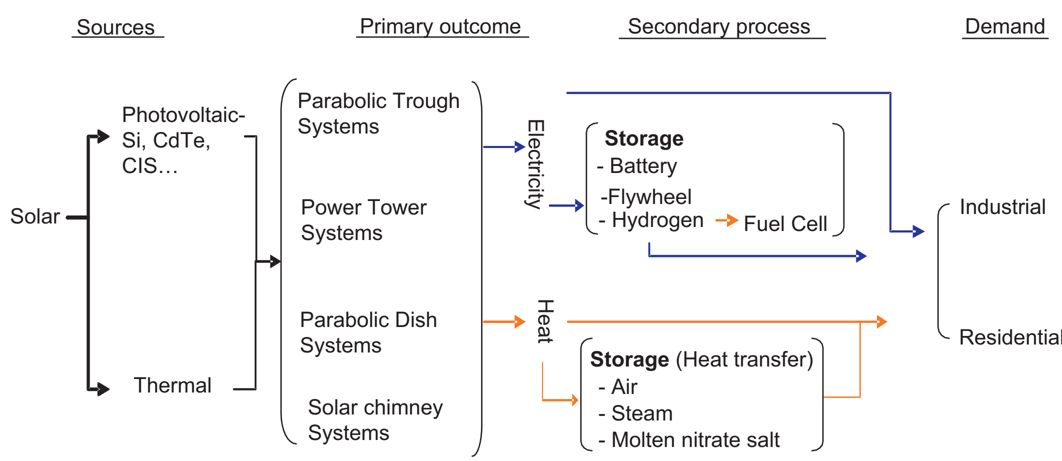


Fig. 7. Solar energy generation flows [14].

solar power than for other REs [21] as shown in Fig. 11. In addition, REs are not only assessed in terms of its performance and investment but also its environmental impacts.

4.2. Technology

State-of-art technologies have furthered the development of the RE industry. In addition to the improvement of conversion efficiency, the growth of the RE industry requires the development of technologies such as energy storage, fuel cells, and hybrid systems that enable RE conversion processes and expansion of RE applications.

4.2.1. Types of storage technologies

According to Akorede et al. [22], energy storage technologies can be classified as battery energy storage systems, flywheels, superconducting magnetic energy storage, compressed air energy storage, and pumped storage. The National Renewable Energy Laboratory (NREL) categorized energy storage into three categories, power quality, bridging power, and energy management, each with a specific range of discharge times that affect and limit its applicability [23]. There are various factors to select an electricity storage technology. They are the storage capacity, duration of discharge, power level, response time, cycle efficiency, and lifetime [24]. According to Denholm et al. [23], "the choice of an energy storage device depends on its application in either the current grid or in the renewable/VG-driven grid; these applications are largely determined by the length of discharge". Table 1 presents a summary of energy storage and applications [23,25].

4.2.2. Fuel cell applications

Fuel-cell technology has been applied for several purposes. The application of this technology was initially limited to space exploration and military purposes, but following years of development, it has been successfully implemented in power generation. Particularly in the automobile industry, fuel cells have

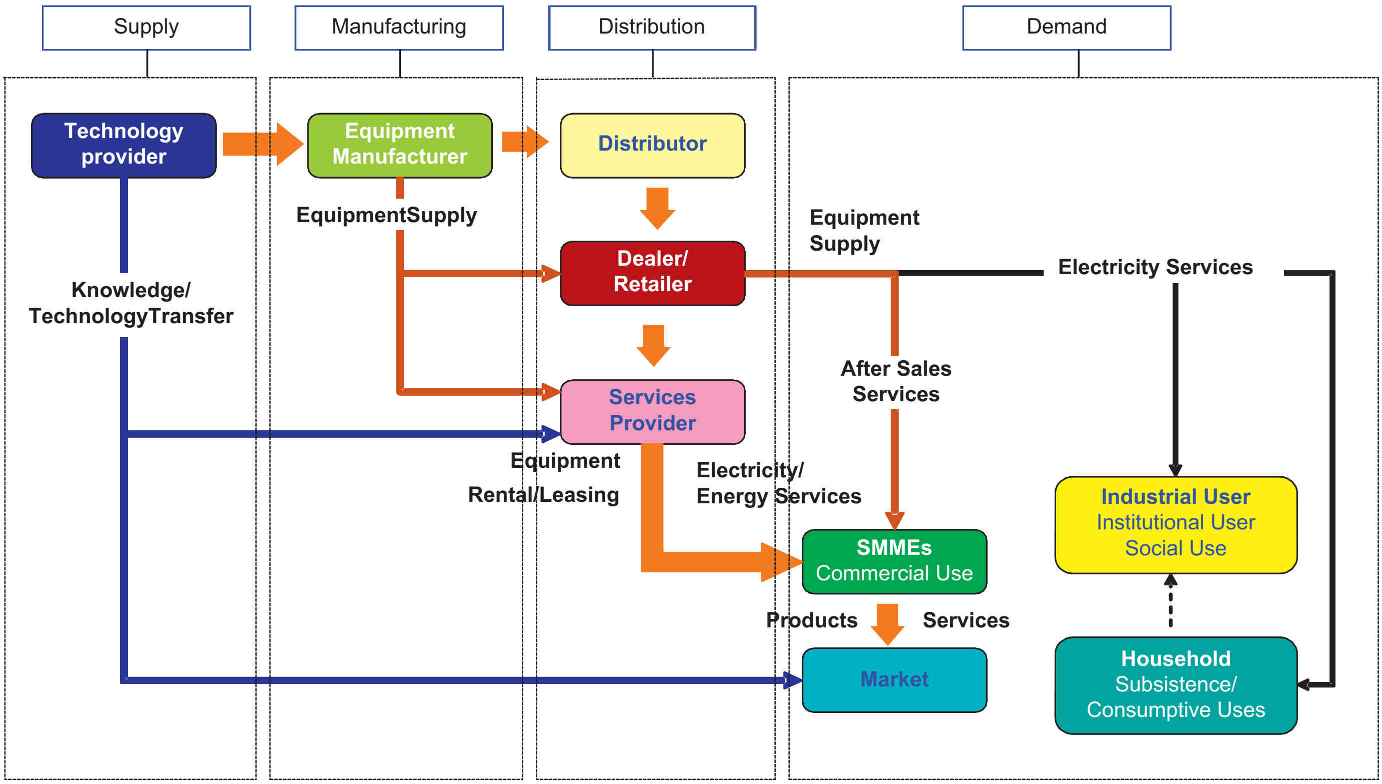


Fig. 8. A pure renewable energy supply chain processes [16].

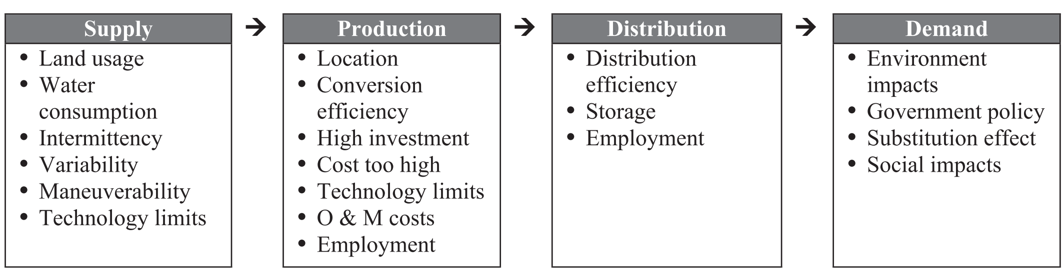


Fig. 9. The concerns of renewable energy [17–19].

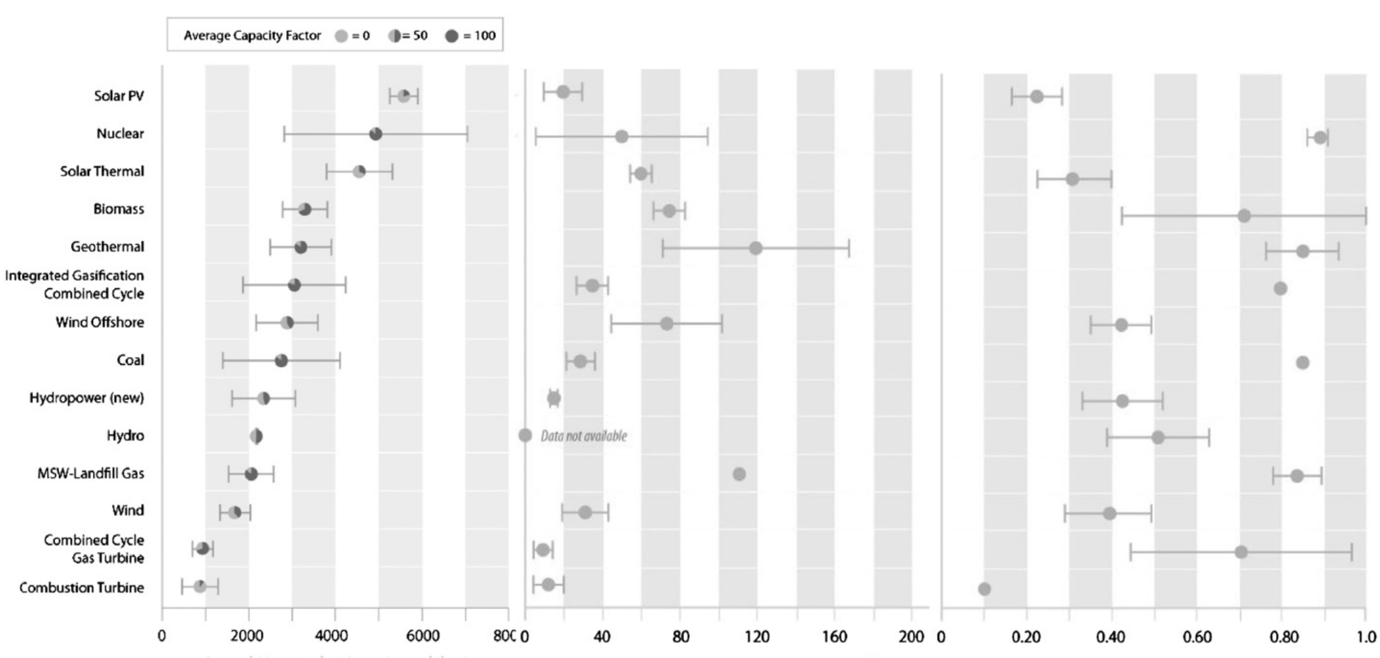
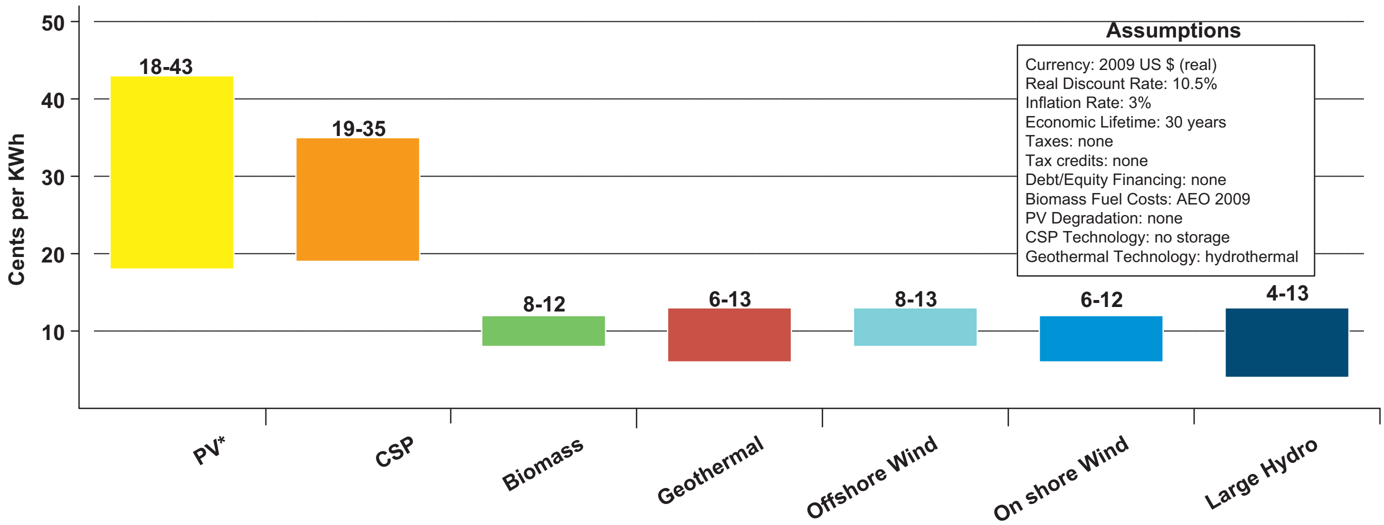


Fig. 10. Energy technology cost and performance data [9].



Current range of utility scale (greater than 5MW) PV in the U.S.

Fig. 11. Levelized cost of energy (LCOE) of renewable electricity by technology (2009) [21].

Table 1
Three classes of energy storage [23,25].

Common name	Example applications	Technology	Discharge time
Power quality	Transient stability, frequency regulation	Flywheel, Capacitor, Superconducting magnetic energy storage	Seconds to minutes
Bridging power	Contingency reserves, ramping	Battery energy storage system -Lead-Acid, Ni–MH, Ni–Cd, Li-Ion	Minutes to 1 h
Energy management	Load leveling, Firm capacity, T&D deferral	Compressed air energy storage, pumped storage, high-energy batteries	Hours

been successfully used in gas-electric hybrid vehicles. Different types of fuel-cell power generators, classified as alkaline fuel cells, polymer-electrolyte-membrane fuel cells, phosphoric-acid fuel cells, molten-carbonate fuel cells, and solid-oxide fuel cells, provide various levels of power. The applications of each fuel-cell technology are based on its energy generation capability and device type (stationary, transportation, portable devices). Table 2 presents the U.S. DoE's comparison of fuel-cell technologies [20].

4.2.3. *Hybrid energy systems*

Hybrid energy systems, which produce electric power and hydrogen simultaneously, play a key role in the "green" transportation industry. For example, Honda has developed a solar-hydrogen power station to support the commercialization of gas-electric hybrid vehicles. Similar systems may be designed for individual usage and to power residential electric appliances. Yilanci et al. [26] described a solar-hydrogen hybrid system that has been applied to fuel cells, gas turbines, internal combustion engines, boilers, and catalytic burners to produce electrical, mechanical, and thermal energies (Fig. 12).

5. Barriers to renewable energy development

The use of RE has enormous benefits. Since each RE type is a natural resource with inconsistent or limited availability, the installation of power-storage facilities in a variety of geographical locations is necessary. However, the development and utilization of REs face many obstacles.

5.1. *Conversion cost*

Conversion efficiency, including primary and secondary conversion processes and distribution, is a major issue in the utilization of RE. A range of associated energy-generation costs requires large investments. Lower conversion cost improves market penetration, but the current conversion cost of REs cannot compete with the traditional energy sources, such as fossil fuels. One of the methods to illustrate the differences of each energy source is the "efficiency coefficient" which is the ratio of the output energy to the input energy [27]. Table 3 presents the efficiency coefficients for each type of power plant (International Atomic Energy Agency, 2002, cited in [27]).

Fossil fuel prices directly affect the price of electric power and have influenced the selling price and consumption of RE. Government policies have been implemented in many countries to improve the gap between these prices through tax refund, certification, or premium price. Fig. 13 shows the sources of income for RE generators [28].

5.2. *Location selection*

Technologies and facilities for RE power generation and conversion should be located near natural sources of RE. Each RE facility should be installed in a strategic location that maximizes the energy collected and the output generated. However, some RE sources have considerable geographical constraints. For example, geothermal resource is available primarily in an area called the "ring of fire", but is usually found along major plate boundaries where earthquakes and volcanoes are concentrated. Tidal-energy generators should be located at coastlines or riversides, wind turbines should be placed in locations with strong winds, and PV solar-cell facilities should be located in high-radiation zones. RE facilities should be placed in locations that ensure the provision of a sufficient and continuous resource supply.

This location selection is similar to the determination of the best manufacturing location for a product, but this involves the consideration of significant costs, such as transportation and

Table 2
Comparison of fuel-cell technologies [20].

Fuel cell type	Common electrolytic	Operating temperature	System output	Electrical efficiency	Combined heat & power efficiency	Applications	Advantages
Polymer electrolyte membrane	Solid organic polymer poly-perfluorosulfonic	50 – 100 °C (122–212 °F)	< 1 kW–250 kW	53–58% (transportation), 25–35% (stationary)	70–90% (low-grade waste heat)	• Backup power • Portable power • Small distributed generation • Transportation, • Specialty vehicles	• Solid electrolytic reduces corrosion & electrolyte management problem • Low temperature • Quick start-up
Alkaline	Aqueous solution of potassium hydroxide soaked in a matrix	90–100 °C (194–212 °F)	10 kW–100 kW	60%	> 80% (low-grade waste heat)	• Military • Space explaoration	• Cathode reaction faster in alkaline electrolyte, leads to higher performance • Can use a variety of catalysts
Phosphoric acid	Liquid phosphoric acid soaked in a matrix	150–200 °C (302–392 °F)	50 kW–1 MW (250 kW module typical)	> 40%	> 85%	• Distributed generation	• Higher overall efficiency with CHP • Increased tolerance to impurities in hydrogen
Molten carbonate	Liquid solution of lithium, sodium, potassium carbonates, soaked in a matrix	600–700 °C (1112–1292 °F)	< 1 kW–1 MW (250 kWmodule typical)	45–47%	> 80%	• Electric utility • Large distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Suitable for CHP
Solid oxide	Yttria stabilized zirconia	650–1000 °C (1202–1832 °F)	< 1 kW–3 MW	35–43%	< 90%	• Auxiliary power • Electric utility • Large distributed generation	• High efficiency • Fuel flexibility • Can use a variety of catalysts • Solid electrolyte reduces electrolyte • MGMT problems • Suitable for CHP • Hybrid/GT cycle

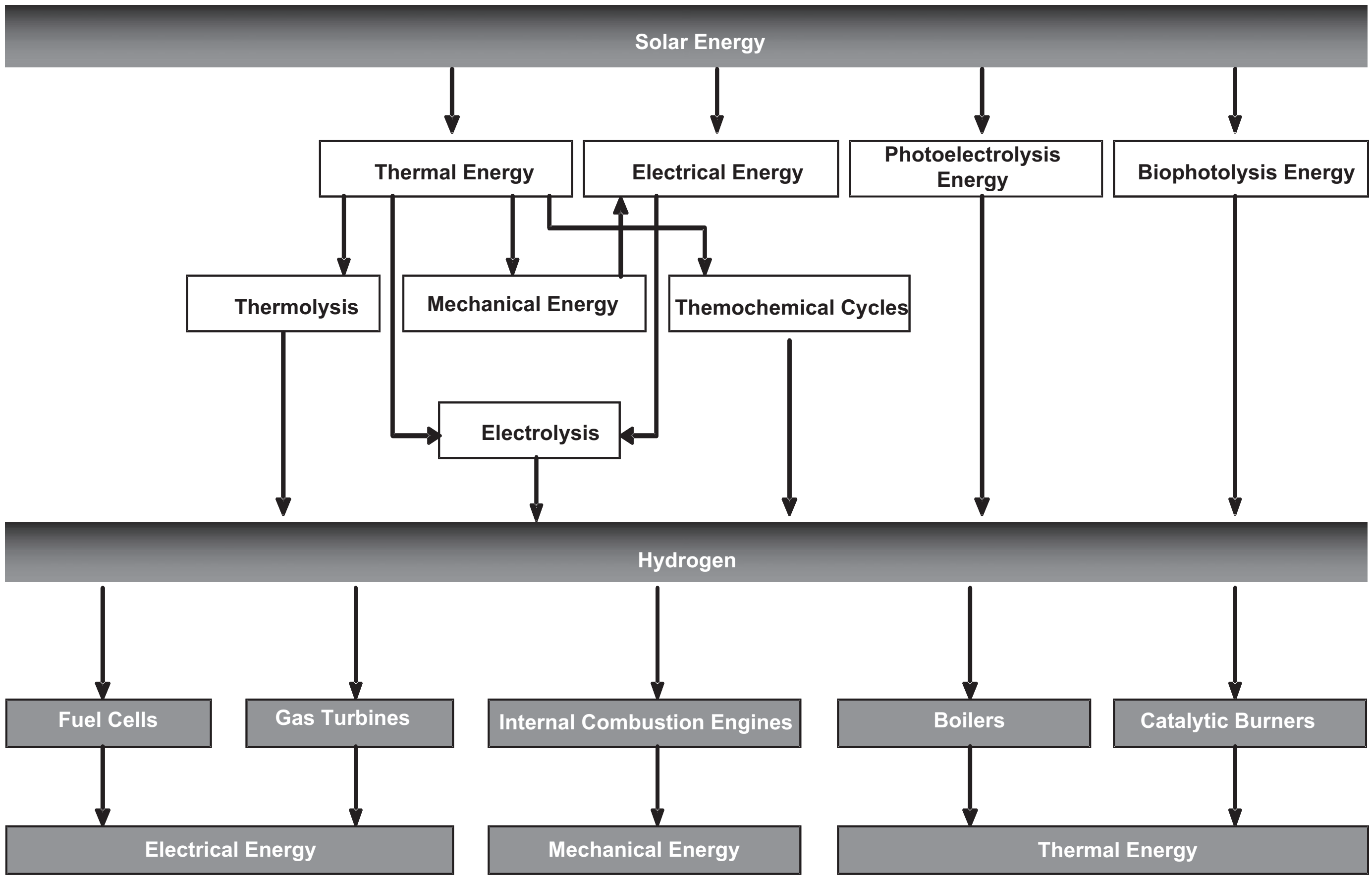


Fig. 12. Production and utilization paths of solar-hydrogen energy [26].

Table 3
Efficiency coefficient of power plants [27].

Type of power plant	Efficiency coefficient (%)
Coal/lignite	39.4
Oil	37.5
Natural gas turbine	39
Natural gas combined cycle	54.8
Nuclear	33.5
Hydroelectric	80
Wind	35
Solar photovoltaic	9.4
Biomass	28
Geothermal	6

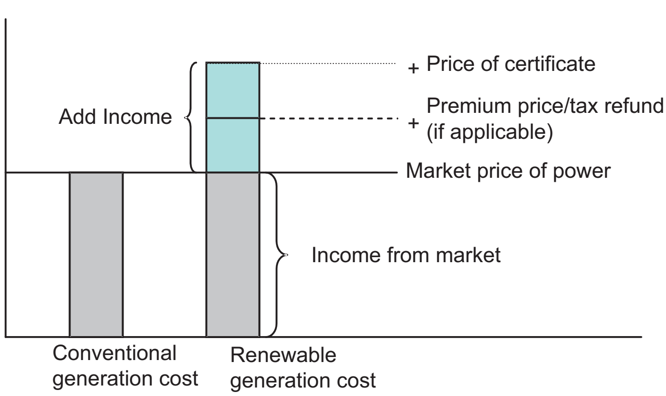


Fig. 13. Sources of income for generators [28].

storage costs. Locations farther from the market entail higher costs. Fig. 14 shows the locations of solar radiation zones and the “ring of fire” around the Pacific rim [29,30].

5.3. Distribution network

The complex distribution network of electrical power results from the need for an efficient system that balances supply and demand and a backup system to manage disruptions due to earthquakes, floods, or fires. RE networks are currently linked with traditional energy networks to support regional power needs. The maximization of RE resource utilization throughout the entire traditional power network presents a challenge for the RE industry. To deliver electricity power to each single user requires a sophisticated distribution network. The RE coupling with other distribution networks should ensure that there is an adequate supply of electrical power to balance the demand fluctuation within a period of time or to balance the intermittent or variability of RE resources. Another important factor is the maneuverability of electricity power implying the rapid response to demand. The traditional fossil power plant is built with a centralized or decentralized network concept for an economic power generation. Once disruptions happen such as the recent tsunami hit in Japan, the control system would not be able to quickly respond and resume back to normal condition.

5.4. Other barriers

The assessment model of Chatzimouratidis and Pilavachi [27] demonstrated the costs for RE development, such as capital investment, operation and maintenance costs, and capacity factor costs. Nevertheless, according to Munashinge and Shearer [17],

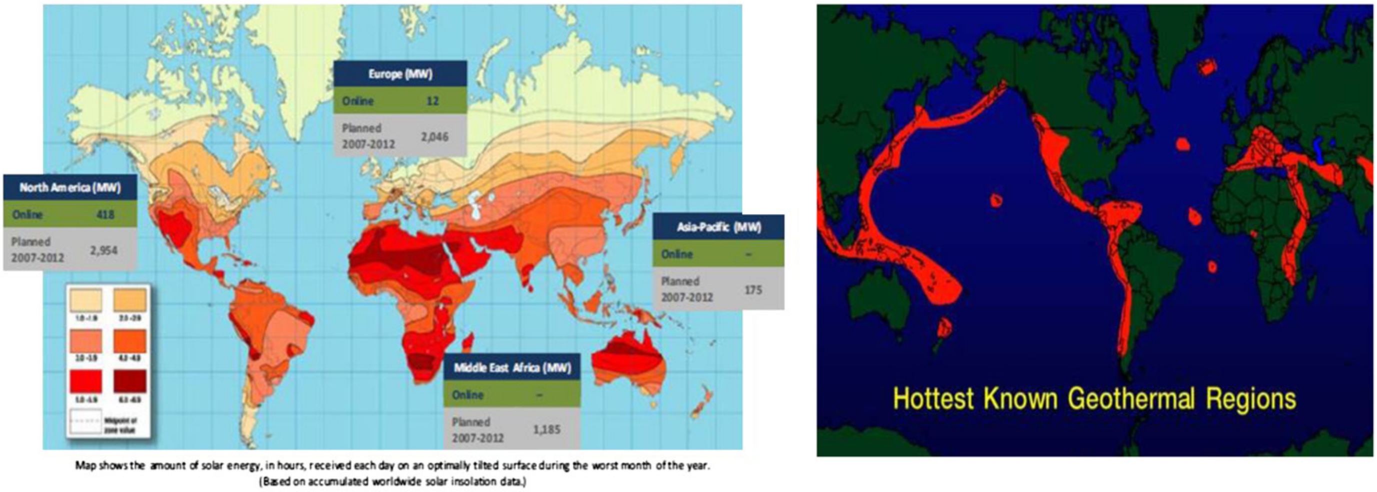


Fig. 14. Solar radiation distribution and geothermal "the ring of fire" [29,30].

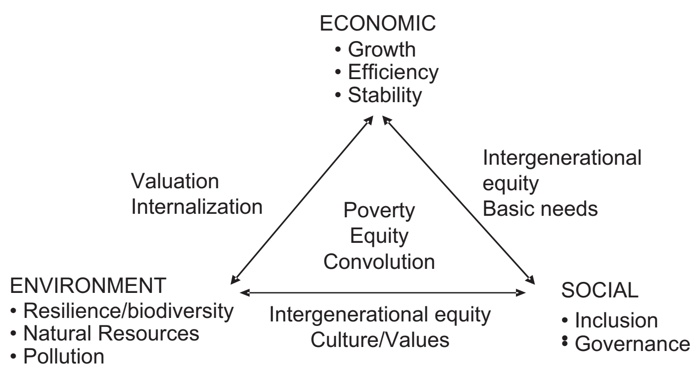


Fig. 15. Three dimensions of sustainability for renewable energy development [17].

Table 4
Energy sources and their potential negative impacts on the environment [32].

Energy sources	Potential negative impacts on the environment
Fossil fuel	Air pollution, acid rains, ozone depletion, global warming potentials.
Hydrogen	Thermal and chemical changes in atmosphere, ozone depletion, influence on microorganisms in the soils and waters, accelerated corrosion of man-made structures.
Wind	Landscape change, soil erosion, reduced air circulation and deterioration of local are quality.
Solar	Landscape change, soil erosion, reduced solar irradiation for plants and vegetation.
Hydro	Change in local eco-systems and local weather conditions, social and cultural impact, induction of earthquake.
Geothermal	Landscape change, underground water resource, acceleration cooling of earth core.
Tidal/wave	Landscape change, reduced water motion/circulation and deterioration of local water quality.
Biofuels	May not be CO_2 natural, may release global warming gases like methane during the production of biofuels, landscape change, deterioration of soil productivity.
Nuclear	Radiation leakage and contamination; the disposal and safe storage of nuclear waste for hundreds of years up to hundred thousand years in geological repositories.

besides the above factors, there are three dimensions of sustainability for RE development as shown in Fig. 15. These are the environmental, economic, and social factors which can be barriers to RE development.

As such, several other barriers have hindered the RE development. According to the Union of Concerned Scientists [31], commercialization, market, and institutional barriers to RE development are present. Commercialization barriers include the underdeveloped infrastructures, lack of economies of scale, unequal government subsidies and taxes, and the failure to market the value and benefits of REs. Market barriers refer to the lack of RE information. While institutional barriers include the small size business, high transaction and financing costs, split incentives, energy transmission costs, and green market restrictions. From the environmental perspective, Li [32] summarized the potential negative impacts of REs as shown in Table 4.

6. Improving the renewable energy supply chain

Barriers to renewable energy development section enumerates the barriers in the development of RE. To overcome these barriers, governmental and scientific research involvement are necessary to improve the RE distribution network and advanced storage technology.

6.1. Involvement of the government and researchers

Government involvement is necessary to provide financial aid and/or tax compensation in the promotion of RE. The governments play a key role in the commercialization of RE to the market. Menz and Vachon [33] defined three aspects of a government policy regime for RE (Fig. 16).

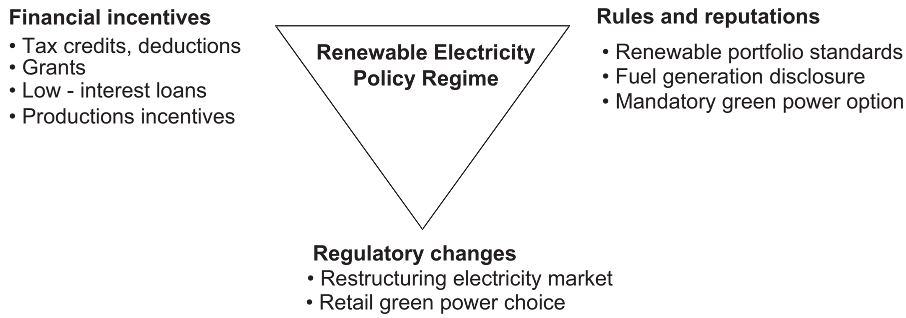


Fig. 16. Renewable electricity policy regime [33].

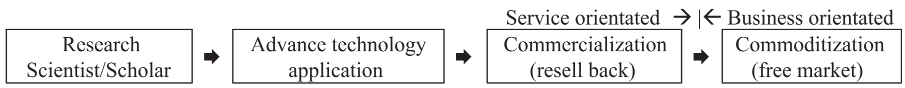


Fig. 17. Renewable energy development stage.

Table 5
Stakeholders in the development and utilization of renewable energies.

International／donors invest
National political officers (legislators, governors)
Public services (ministry of health, social security agency, ministry of finance)
Scientific researchers
Renewable-energy generators and investors
Local population
Substitute energies
Labor (unions, medical associations)
Commercial/private for-profit organizations
Nonprofit (nongovernmental) organizations, foundations
Civil society
Users/consumers

Scientific research plays important roles by implementing efficient conversion processes, creating and employing advanced technologies that reduce the cost of RE and facilitate the construction of an efficient RE supply chain.

6.2. Commercializing the use of renewable energy

The utilization of RE is triggered by the desire to improve environmental conditions. RE conversion designs have been included in the technology of turbines, thin-film PV cells, and other devices. To promote market acceptance and use, RE should become an affordable economic commodity. Such development would increase market consumption and replace the use of fossil-fuel energy in the future, as illustrated in Fig. 17.

A hybrid system has been developed to expand the utilization of RE. For example, hydrogen is an RE resource that can replace fossil fuels, and has a storage system that supports industrial and residential power needs. Hydrogen can also be converted from solar, wind, water, or geothermal processes during the off-peak period. There are other outcomes which can be generated from biomass such as bioethanol or biodiesel and fertilizers. These outcomes can be offered to the market like other commodities.

6.3. Realizing the value of renewable energies

The promotion of RE depends upon stakeholders' understanding of its profit and value. Stakeholders have a vested interest in the promotion of a policy, such as the generation and utilization of RE. These stakeholders can be grouped into the categories shown in Table 5.

Porter [34] developed a value chain that links all stakeholders in the fulfillment of customers' needs. The value identification of customers and stakeholders determines a business strategy and target profit performance. According to Loucopoulos and Karakostas [35], value refers to the relative usefulness of an object. In the case of a product or business, value defines the relative benefit of acquiring a product, or of the existence of a particular business. The RE supply chain consists of many stakeholders with different roles. Fig. 18 shows the stakeholders and values of RE in the supply chain [19,33,36,37].

6.4. Distribution network

According to Denholm [23], RE sources should employ highly efficient operation processes to cope with the uncertainty of supply and demand. Jones et al. [38] described decoupling points to support supply efficiency and flexibility in meeting customer needs. They suggested that such decoupling would provide a flexible distribution network that supports a lean-agile supply chain system (Fig. 19). The ability to maneuver electrical power to rapidly respond to demand should also be considered. Moreover, the efficiency of electrical distribution may be improved through the utilization of smart grids, which monitor the energy distribution network to maximize power utilization.

6.4.1. Smart grids

According to the National Electrical Manufacturers Association [39], "the basic concept of Smart Grid is to improve reliability, maximize throughput, increase energy efficiency, provide consumer participation and allow diverse generation and storage options". The Korea Smart Grid Institute [40] defined smart grids as a technology that integrates information technologies with power networks to optimize energy efficiency through the interactive exchange of real-time information between suppliers and consumers. Smart grids are useful IT systems to monitor and control electricity distribution. It also facilitates financial control function for energy providers as well as users. To achieve this, the information collected from each user in the chain must be well-managed and properly structured.

6.4.2. Centralized, decentralized, and distributed energy networks

Most traditional power plants utilize centralized networks. When disruptions occur, such networks cannot respond rapidly to

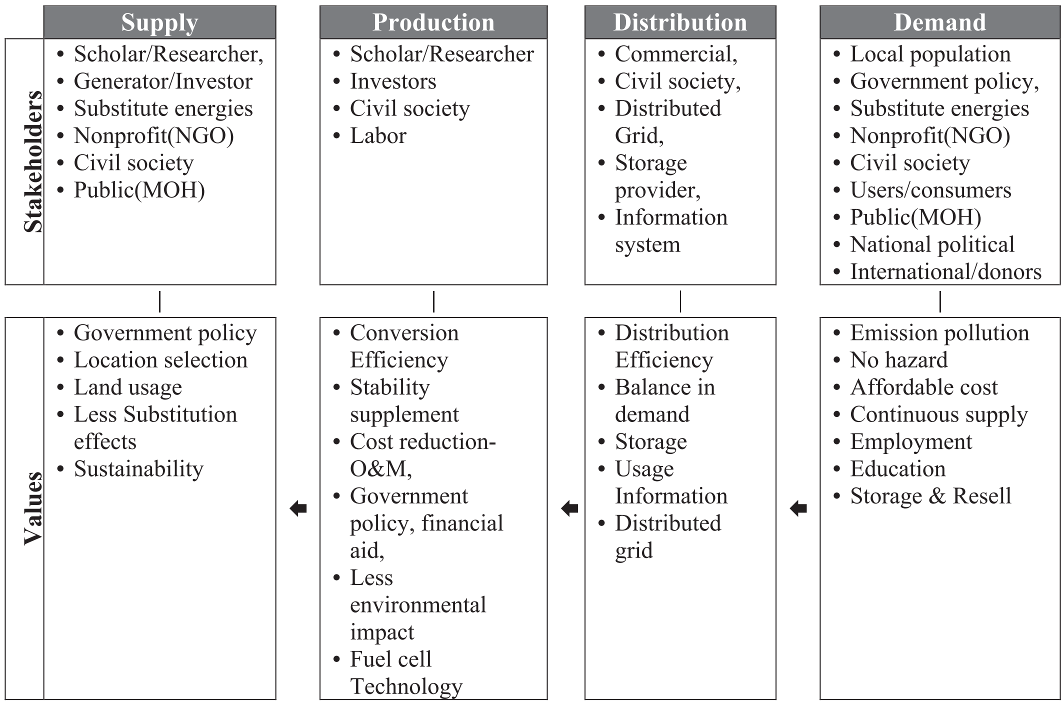


Fig. 18. The stakeholders and the values of renewable energy supply chain [19,33,36,37].

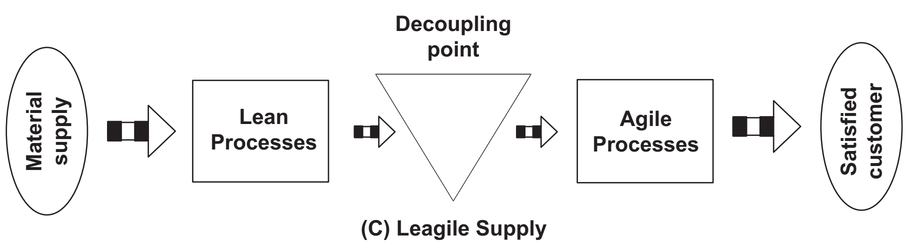


Fig. 19. A decoupling distribution networks [38].

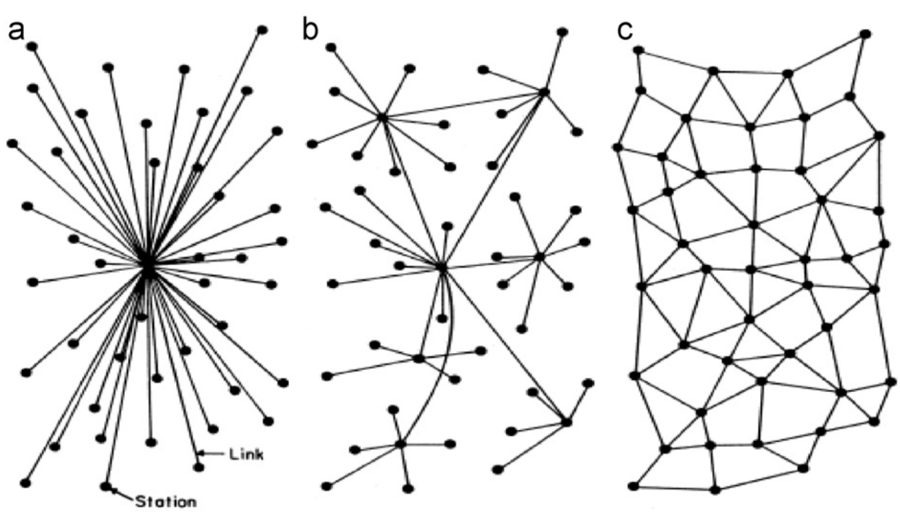


Fig. 20. Distribution network [41]. (a) Centralized, (b) decentralized and (c) distributed.

make necessary changes or resume normal operation. For example, Japan Fukushima nuclear power plants were damaged by the tsunami that caused serious impact on industry productivity due to power shortage. Decentralized networks consist of several centralized sub-networks, each covering a specific area of distribution that is commonly limited by geographical location. Similar to the centralized network, if one sub-network failed, the subsidiary would not be able to get support from other energy network. Given these limitations, distributed-energy-generation networks have been restricted in U.S.A. and Europe for decades.

Table 6
Storage technologies [42].

Category	Technology type	System energy density	Efficiency of recovery	Illustrative economic costs	Advantage	Disadvantage	Suitable for Energy MGMT	Power quality	Transport
Advanced battery systems	Super capacitors	0.1–5 Wh/kg	85–98%	2002: 200–1000 (€/kWh)	Long life cycle, high effciency	Low energy density Toxic and corrosive compounds	**	***	***
	Nickel Batteries	20–120 Wh/kg	60–91%	200–750 (€/kW h)	High power and energy densities, Good efficiency	NiCd: Cadmium highly toxic, NiZn, NiMH and Na-NiCl2 require recycling	**	***	***
	Lithium Batteries	80–150 Wh/kg	90–100%	150–250 (€/kW h)	High power and energy densities, High efficiency	High cost, Lithium oxides & salt require recycling, polymer solvents and carbon must be made inert	*	***	***
	Lead-acid batteries	25–45 Wh/kg	60–95%	50–150 (€/kW h)	Low capital cost	Lead requires recycling	**	***	***
	Zinc-Bromine flow batteries	37 Wh/kg	75%	2 MW h battery (1.8 m€)	High capacity	Low energy density	***	**	
	Vanadium flow batteries		85%	1280 €/kW	High capacity	Low energt denisty	***	**	
	Metal-air batteries	110–420 Wh/kg	~50%		High energy density, Low cost, Environmentally benign	Poor electrical rechargeability, short recharge lifetime	***	*	*
	Sodium-sulphur batteries	150–240 Wh/kg	> 86%	170 €/kW	High power and energy denities High efficency	High production cost, Na requires recycling	***	**	*
Fluid Storage	Pumped hydro-electric	N/A	75–85%	140 m- > 680 m € for a 1000 MW plant	High capacity, relatively low cost per unit capacity	Disturds local wildlife and water levels	***	**	X
	Compressed air energy systems	N/A	80%	400€/kW h at plant	High capacity, relatively low cost per unit capacity	Problematic in obtaining sites for use,	***	**	*X*
Mechanical Systems	Flywheel	30–100 Wh/kg	90%	3,000–10,000 (€/kW h)	High power	Low energy density	**	***	*
Electro-Magnetic Systems	Supper conducting magnets		97–98%	350 €/kW h at plant	High power	Health impacts for large sacle sites	*	***	*X*
Hydrogen	H_2 fuel cell	1 KW–3 MW	25–58%	6,000–30,000 (€/kW h)	Can be stored longterm, Range of cell types for different applications	Expensive catalysis or processing often required	***	***	***
	H_2 internal combustion engine(ICE)	N/A	N/A				*	*	***

* = level of utilization.
** *X* = not applicable.

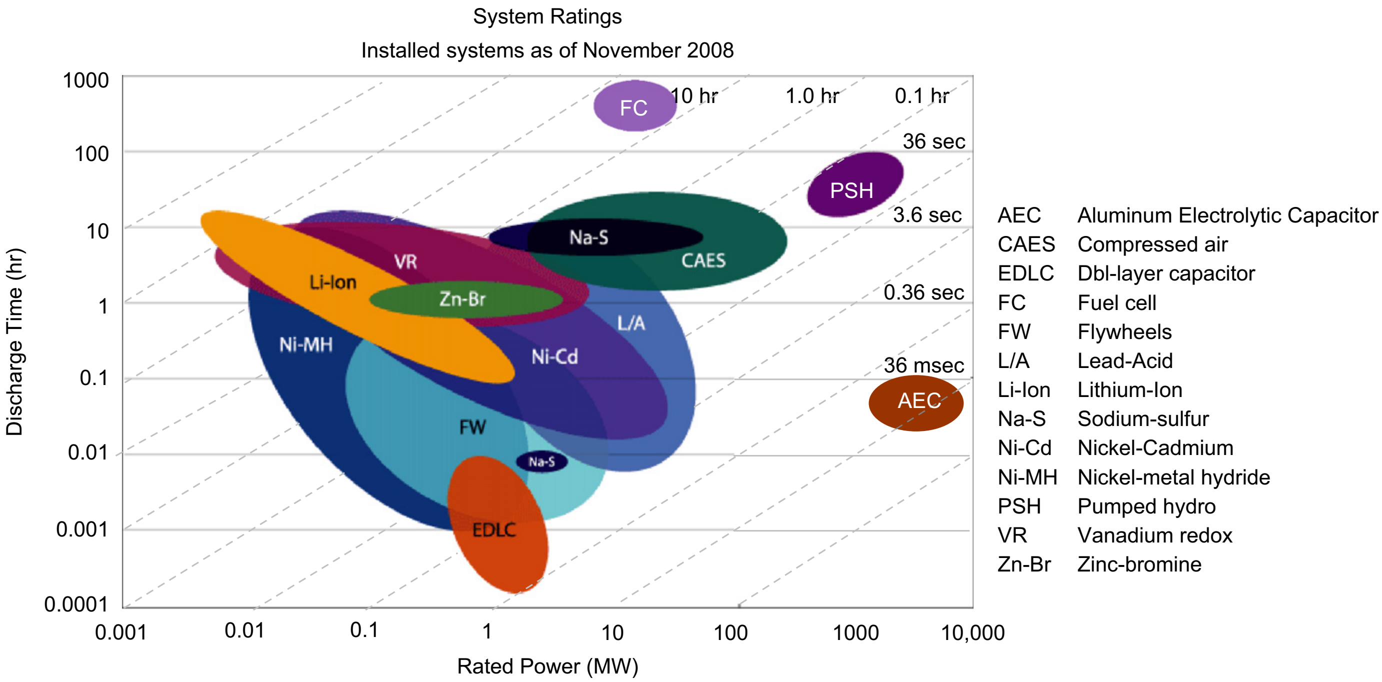


Fig. 21. Ragone plot evaluation for storage technology selection [25,43].

Power distributors in these networks are interconnected to the main distribution network, as shown in Fig. 20 [41].

6.5. *Selecting storage technologies*

Storage systems are key technologies in the RE development because they support energy during intermittent supply and demand. Storage systems may also be used for the conversion of primary energy into another energy forms such as steam and hydrogen. Naish [42] classified storage technologies into five categories: advanced battery systems, fluid storage, mechanical systems, electro-magnetic systems, and hydrogen. Suitable applications of these storage systems are shown in Table 6.

There are other evaluation criteria for selecting a storage technology. The Electricity Storage Association [25] provided four categories for the evaluation of economic applications of storage technologies: size and weight, capital cost, line efficiency, and per-cycle cost. Storage technologies may also be evaluated using the Ragone plots, which incorporate energy density, power density, and discharge times as selection parameters [25,43] as shown in Fig. 21.

7. Conclusions

This study assesses the RE sources focusing on the RE supply chain, the performance and barriers to the RE development; we then suggest for improvement the RE generation and utilization. Government and research institute involvement, commoditization of RE, realization of RE value, improvement of distribution networks, and the development of advanced storage technology are the recommended strategies for the further development of RE. The identified barriers to the generation and utilization of REs are the conversion cost, location constraints, complex distribution networks and other considerable barriers. These barriers may be resolved through the involvement of governments, researchers, and stakeholders in the development of RE.

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